

jc849 U.S. PTO
10/03/00

10-04-00

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Docket No. 4714 P1/AMI-00-11

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Box Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231

Re: Inventors: Ming Xi, Ashok Sinha, Moris Kori, Alfred W. Mak, Jeong Soo Byun, Lawrence Chung-Lai Lei, Hua Chung
Title: METHOD AND APPARATUS FOR DEPOSITING REFRACTORY METAL LAYERS EMPLOYING SEQUENTIAL DEPOSITION TECHNIQUES TO FORM A NUCLEATION LAYER

Transmitted herewith is the patent application identified above, including:

- ☒ Specification, claims and abstract, totaling 15 pages, excluding Title Sheet.
- ☒ Drawings totaling 9 pages, ___ Formal ☒ Informal.
- ☒ Declaration and Power of Attorney (unsigned)
- ☒ Assignment of the invention to Applied Materials, Inc. (unexecuted)
- ☒ Assignment Recordation Cover Sheet

JC914 U.S. PTO
09/678266
10/03/00

FEE CALCULATION

Fee Items	Claims Filed	Included With Basic Fee	Extra Claims	Fee Rate	Total
Total Claims 20	20	20-20=0	0	X \$	--
Independent Claims	4	4	0	\$ 0	\$0
Basic Filing Fee				\$0	\$0
TOTAL FEES					

- ☐ The Commissioner is hereby authorized to charge \$0 to Deposit Account No.
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PATENT COUNSEL
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Santa Clara, CA. 95052

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Date of Deposit October 3, 2000
Signature: Kenneth C. Brooks

Respectfully submitted,

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PATENT APPLICATION

**METHOD AND APPARATUS FOR DEPOSITING REFRACTORY METAL
LAYERS EMPLOYING SEQUENTIAL DEPOSITION TECHNIQUES TO FORM
A NUCLEATION LAYER**

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METHOD AND APPARATUS FOR DEPOSITING REFRACTORY METAL LAYERS EMPLOYING SEQUENTIAL DEPOSITION TECHNIQUES TO FORM A NUCLEATION LAYER

BACKGROUND OF THE DISCLOSURE

5 Field of the Invention

This invention relates to the processing of semiconductor substrates. More particularly, this invention relates to improvements in the process of depositing refractory metal layers on semiconductor substrates.

Description of the Related Art

10 The semiconductor processing industry continues to strive for larger production yields while increasing the uniformity of layers deposited on substrates having larger surface areas. These same factors in combination with new materials also provide higher integration of circuits per unit area of the substrate. As circuit integration increases, the need for greater uniformity and process control regarding layer thickness rises. As a
15 result, various technologies have been developed to deposit layers on substrates in a cost-effective manner, while maintaining control over the characteristics of the layer. Chemical Vapor Deposition (CVD) is one of the most common deposition processes employed for depositing layers on a substrate. CVD is a flux-dependent deposition technique that requires precise control of the substrate temperature and precursors
20 introduced into the processing chamber in order to produce a desired layer of uniform thickness. These requirements become more critical as substrate size increases, creating a need for more complexity in chamber design and gas flow technique to maintain adequate uniformity.

A variant of CVD that demonstrates superior step coverage, compared to CVD, is
25 Atomic Layer Deposition (ALD). ALD is based upon Atomic Layer Epitaxy (ALE) that was employed originally to fabricate electroluminescent displays. ALD employs chemisorption to deposit a saturated monolayer of reactive precursor molecules on a substrate surface. This is achieved by alternately pulsing an appropriate reactive precursor into a deposition chamber. Each injection of a reactive precursor is separated
30 by an inert gas purge to provide a new atomic layer additive to previously deposited

layers to form a uniform layer on the substrate. The cycle is repeated to form the layer to a desired thickness. A drawback with ALD techniques is that the deposition rate is much lower than typical CVD techniques by at least one order of magnitude.

Formation of film layers at a high deposition rate while providing adequate step coverage are conflicting characteristics often necessitating sacrificing one to obtain the other. This conflict is true particularly when refractory metal layers are deposited to cover gaps or vias during formation of contacts that interconnect adjacent metallic layers separated by dielectric layers. Historically, CVD techniques have been employed to deposit conductive material such as refractory metals in order to inexpensively and quickly form contacts. Due to the increasing integration of semiconductor circuitry, tungsten has been used based upon superior step coverage. As a result, deposition of tungsten employing CVD techniques enjoys wide application in semiconductor processing due to the high throughput of the process.

Depositing tungsten by traditional CVD methods, however, is attendant with several disadvantages. For example, blanket deposition of a tungsten layer on a semiconductor wafer is time-consuming at temperatures below 400° C. The deposition rate of tungsten may be improved by increasing the deposition temperature to, e.g., about 500° C to about 550° C; however, temperatures in this higher range may compromise the structural and operational integrity of the underlying portions of the integrated circuit being formed. Use of tungsten has also frustrated photolithography steps during the manufacturing process as it results in a relatively rough surface having a reflectivity of 20% or less than that of a silicon substrate. Finally, tungsten has proven difficult to deposit uniformly. Variance in film thickness of greater than 1% has been shown with tungsten, thereby frustrating control of the resistivity of the layer. Several prior attempts to overcome the aforementioned drawbacks have been attempted.

For example, in United States patent number 5,028,565 to Chang et al., which is assigned to the assignee of the present invention, a method is disclosed to improve, inter alia, uniformity of tungsten layers by varying the deposition chemistry. The method includes, in pertinent part, formation of a nucleation layer over an intermediate, barrier layer before depositing the tungsten layer via bulk deposition. The nucleation layer is formed from a gaseous mixture of tungsten hexafluoride, hydrogen, silane and argon.

The nucleation layer is described as providing a layer of growth sites to promote uniform deposition of a tungsten layer thereon. The benefits provided by the nucleation layer are described as being dependent upon the barrier layer present. For example, were the barrier layer formed from titanium nitride, the tungsten layer's thickness uniformity is improved as much as 15%. Were the barrier layer formed from sputtered tungsten or sputtered titanium tungsten, the benefits provided by the nucleation layer are not as pronounced.

United States patent number 5,879,459 to Gadgil et al. discloses an apparatus that takes advantage of ALD. To that end, the apparatus, a low profile, compact atomic layer deposition reactor (LP-CAR), has a body with a substrate processing region adapted to serve a single substrate or a planar array of substrates, as well as a valve, and a port for substrate loading and unloading. In some embodiments multiple reactors are stacked vertically and share a common robotic handler interface with a CVD system. In this manner, the robotic handler may manipulate substrates associated with both the CVD system and the LP-CAR. The compact reactor is distinguished by having individual injectors, each of which comprises a charge tube formed between a charge valve and an injection valve. The charge valve connects the charge tube to a pressure regulated supply, and the injection valve opens the charge tube into the compact reactor. Rapidly cycling the valves injects fixed mass-charges of gas or vapor into the compact reactor.

What is needed, however, is a technique to deposit conductive layers having a deposition rate comparable to CVD techniques while providing the step coverage associated with ALD techniques.

SUMMARY OF THE INVENTION

A method and system to form a refractory metal layer on a substrate features nucleating a substrate using sequential deposition techniques in which the substrate is serially exposed to first and second reactive gases followed by forming a layer, employing vapor deposition, to subject the nucleation layer to a bulk deposition of a compound contained in one of the first and second reactive gases. To that end, the system includes a processing chamber that has a holder disposed therein to support the substrate. A gas delivery system and a pressure control system is in fluid communication with the

processing chamber. A temperature control system is in thermal communication therewith. A controller is in electrical communication with gas delivery systems, temperature control systems and pressure control systems. A memory is in data communication with the controller. The memory comprises a computer-readable medium
 5 having a computer-readable program embodied therein. The computer-readable program includes instructions for controlling the operation of the processing chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a semiconductor processing system in accordance
 10 with the present invention;

Fig. 2 is a detailed view of the processing chambers shown above in Fig. 1;

Fig. 3 is a schematic view showing deposition of a first molecule onto a substrate during ALD;

Fig. 4 is a schematic view showing deposition of second molecule onto a substrate
 15 during ALD to form a refractory metal layer;

Fig. 5 is a graphical representation showing the concentration of gases, introduced into the processing chamber shown above in Fig. 2, and the time in which the gases are present in the processing chamber, in accordance with the present invention;

Fig. 6 is a graphical representation showing the relationship between the number
 20 of ALD cycles and the thickness of a layer formed on a substrate employing ALD, in accordance with the present invention;

Fig. 7 is a graphical representation showing the relationship between the number of ALD cycles and the resistivity of a layer formed on a substrate employing ALD, in accordance with the present invention;

Fig. 8 is a graphical representation showing the relationship between the
 25 deposition rate of a layer formed on a substrate employing ALD and the temperature of the substrate;

Fig. 9 is a graphical representation showing the relationship between the resistivity of a layer formed on a substrate employing ALD and the temperature of the substrate, in accordance with the present invention;

Fig. 10 is a cross-sectional view of a patterned substrate having a nucleation layer
5 formed thereon employing ALD, in accordance with the present invention;

Fig. 11 is a partial cross-sectional view of the substrate, shown above in Fig. 10, with a refractory metal layer formed atop of the nucleation layer employing CVD, in accordance with the present invention; and

Fig. 12 is a graphical representation showing the concentration of gases shown
10 above in Fig. 3 in accordance with a first alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, an exemplary wafer processing system includes one or more processing chambers 12 and 14 disposed in a common work area 16 surrounded by a wall
15 18. The processing chambers 12 and 14 are in data communication with a controller 22 that is connected to one or more monitors, shown as 24 and 26. The monitors typically display common information concerning the process associated with the processing chamber 12 and 14. One of the monitors 26 is mounted to the wall 18, with the remaining monitor 24 being disposed in the work area 16. Operational control of the processing
20 chambers 12 and 14 may be achieved by the use of a light pen, associated with one of the monitors 24 and 26, to communicate with the controller 22. For example, light pen 28 is associated with monitor 24 and facilitates communication with the controller 22 through monitor 24. Light pen 39 facilitates communication with the controller 22 through monitor 26.

Referring both the to Figs. 1 and 2, each of the processing chambers 12 and 14 includes a housing 30 having a base wall 32, a cover 34, disposed opposite to the base wall 32, and a sidewall 36, extending therebetween. The housing 30 defines a chamber 37, and a pedestal 38 is disposed within the processing chamber 37 to support a substrate 42, such as a semiconductor wafer. The pedestal 38 may be mounted to move between
30 the cover 34 and the base wall 32, using a displacement mechanism (not shown), but the

position thereof is typically fixed. Supplies of processing gases 39a, 39b and 39c are in fluid communication with the processing chamber 37 via a showerhead 40. Regulation of the flow of gases from the supplies 39a, 39b and 39c is effectuated via flow valves 41.

Depending on the specific process, the substrate 42 may be heated to a desired temperature prior to layer deposition via a heater embedded within the pedestal 38. For example, the pedestal 38 may be resistively heated by applying an electric current from an AC power supply 43 to the heater element 44. The substrate 42 is, in turn, heated by the pedestal 38, and can be maintained within a desired process temperature range of, for example, about 20 °C to about 750 °C. A temperature sensor 46, such as a thermocouple, is also embedded in the wafer support pedestal 38 to monitor the temperature of the pedestal 38 in a conventional manner. For example, the measured temperature may be used in a feedback loop to control the electrical current applied to the heater element 44 by the power supply 43 such that the substrate temperature can be maintained or controlled at a desired temperature that is suitable for the particular process application. Optionally, the pedestal 38 may be heated using radiant heat (not shown). A vacuum pump 48 is used to evacuate the processing chamber 37 and to help maintain the proper gas flows and pressure inside the processing chamber 37.

Referring to Figs. 1 and 3, one or both of the processing chambers 12 and 14, discussed above may operate to deposit refractory metal layers on the substrate employing sequential deposition techniques. One example of sequential deposition techniques in accordance with the present invention includes atomic layer deposition. Depending on the specific stage of processing, the refractory metal layer may be deposited on the material from which the substrate 42 is fabricated, e.g., SiO₂. The refractory metal layer may also be deposited on a layer previously formed on the substrate 42, e.g., titanium, titanium nitride and the like.

During the sequential deposition technique in accordance with the present invention, a batch of a first processing gas, in this case Aa_x, results in a layer of A being deposited on the substrate 42 having a surface of ligand x exposed to the processing chamber 37. Thereafter, a purge gas enters the processing chamber 37 to purge the gas Aa_x. After purging gas Aa_x from the processing chamber 37, a second batch of processing gas, Bb_y, is introduced into the processing chamber 37. The a ligand present on the substrate surface reacts with the b ligand and B atom on the, releasing molecules ab and Ba, that move away from the substrate 42 and are subsequently pumped from the

processing chamber 37. In this manner, a surface comprising a layer of A compound remains upon the substrate 42 and exposed to the processing chamber 37, shown in Fig. 4. The composition of the layer of A compound may be a monolayer of atoms typically formed employing ATD techniques. Alternatively, the layer of compound A may include
 5 a layer of multiple atoms. In such as case, the first processing gases may include a mixture of process gases each of which has atoms that would adhere to the substrate 42. The process proceeds cycle after cycle, until the desired thickness is achieved.

Referring to both Figs. 2 and 5, although any type of processing gas may be employed, in the present example, the processing gas Aa_x includes WF_6 and the
 10 processing gas Bb_y is B_2H_6 . Two purge gases are employed: Ar and N_2 . Each of the processing gases was flowed into the processing chamber 37 with a carrier gas, which in this example were one of the purge gases: WF_6 is introduced with Ar and B_2H_6 is introduced with N_2 . It should be understood, however, that the purge gas may differ from the carrier gas, discussed more fully below. One cycle of the ALD technique in
 15 accordance with the present invention includes flowing the purge gas, N_2 , into the processing chamber 37 during time t_1 , which is approximately 0.01 to 15 seconds before B_2H_6 is flowed into the processing chamber 37. During time t_2 , the processing gas B_2H_6 is flowed into the processing chamber 37 for a time in the range of 0.01 to 15 seconds, along with a carrier gas, which in this example is N_2 . After 0.01 to 15 seconds have
 20 lapsed, the flow of B_2H_6 terminates and the flow of N_2 continues during time t_3 for an additional time in the range of 0.01 to 15 seconds, purging the processing chamber of B_2H_6 . During time t_4 , the processing chamber 37 is pumped so as to remove most, if not all, gases. After pumping of the process chamber 37, the carrier gas Ar is introduced for a time in the range of 0.01 to 15 seconds during time t_5 , after which time the process gas
 25 WF_6 is introduced into the processing chamber 37, along with the carrier gas Ar during time t_6 . The time t_6 lasts between 0.01 to 15 seconds. The flow of the processing gas WF_6 into the processing chamber 37 is terminated approximately 0.01 to 15 seconds after it commenced. After the flow of WF_6 into the processing chamber 37 terminates, the flow of Ar continues for an additional time in the range of 0.01 to 15 seconds, during time
 30 t_7 . Thereafter, the processing chamber 37 is pumped so as to remove most, if not all, gases therein, during time t_8 . As before, the pumping process lasts approximately thirty seconds, thereby concluding one cycle of the sequential deposition technique in accordance with the present invention.

The benefits of employing the sequential deposition technique are manifold, including flux-independence of layer formation that provides uniformity of deposition independent of the size of a substrate. For example, the measured difference of the layer uniformity and thickness measured between a 200 mm substrate and a 32 mm substrate deposited in the same chamber is negligible. This is due to the self-limiting characteristics of the sequential deposition techniques. Further, this technique contributes to a near-perfect step coverage over complex topography.

In addition, the thickness of the layer B, shown in Fig. 4, may be easily controlled while minimizing the resistance of the same by employing sequential deposition techniques. With reference to Fig. 6 it is seen in the slope of line 50 that the thickness of the tungsten layer B is proportional to the number of cycles employed to form the same. The resistivity of the tungsten layer, however, is relatively independent of the thickness of the layer, as shown by the slope of line 52 in Fig. 7. Thus, employing sequential deposition techniques, the thickness of a refractory metal layer may be easily controlled as a function of the cycling of the process gases introduced into the processing chamber with a negligible effect on the resistivity.

Referring to Fig. 8, control of the deposition rate was found to be dependent upon the temperature of the substrate 42. As shown by the slope of line 54, increasing the temperature of the substrate 42 increased the deposition rate of the tungsten layer B. For example, at 56, the deposition rate is shown to be approximately 2 Å/cycle at 250° C. However at point 56 the deposition rate is approximately 5 Å/cycle at a temperature of 450° C. The resistivity of the tungsten layer, however, is virtually independent of the layer thickness, as shown by the slope of curve 58, shown in Fig. 9. As a result, the deposition rate of the tungsten layer may be controlled as a function of temperature without compromising the resistivity of the same. However, it may be desired to reduce the time necessary to deposit an entire layer of a refractory metal.

To that end, a bulk deposition of the refractory metal layer may be included in the deposition process. Typically, the bulk deposition of the refractory metal occurs after the nucleation layer is formed in a common processing chamber. Specifically, in the present example, nucleation of a tungsten layer occurs in chamber 12 employing the sequential deposition techniques discussed above, with the substrate 42 being heated in the range of 200° C to 400° C, and the processing chamber 37 being pressurized in the range of 1 to 10 Torr. A nucleation layer 60 of approximately 12 to 20 nm is formed on a patterned

substrate 42, shown in Fig. 10. As shown, the substrate 42 includes a barrier layer 61 and a patterned layer having a plurality of vias 63. The nucleation layer is formed adjacent to the patterned layer covering the vias 63. As shown, forming the nucleation layer 60 employing ALD techniques provides 100% step coverage. To decrease the time required to form a complete layer of tungsten, a bulk deposition of tungsten onto the nucleation layer 60 occurs using CVD techniques, while the substrate 42 is disposed in the same processing chamber 12, shown in Fig. 1. The bulk deposition may be performed using recipes well known in the art. In this manner, a tungsten layer 65 providing a complete plug fill is achieved on the patterned layer with vias having aspect ratios of approximately 6:1, shown in Fig. 11.

As mentioned above, in an alternate embodiment of the present invention, the carrier gas may differ from the purge gas, as shown in Fig. 12. The purge gas, which is introduced at time intervals t_1 , t_3 , t_5 and t_7 comprises of Ar. The carrier gas, which is introduced at time intervals t_2 and t_6 , comprises of N_2 . Thus, at time interval t_2 the gases introduced into the processing chamber include a mixture of B_2H_6 and N_2 , and a time interval t_6 , the gas mixture includes WF_6 and N_2 . The pump process during time intervals t_4 and t_8 is identical to the pump process discussed above with respect to Fig. 5.

Referring again to Fig. 2, the process for depositing the tungsten layer may be controlled using a computer program product that is executed by the controller 22. To that end, the controller 22 includes a central processing unit (CPU) 70, a volatile memory, such as a random access memory (RAM) 72 and permanent storage media, such as a floppy disk drive for use with a floppy diskette, or hard disk drive 74. The computer program code can be written in any conventional computer readable programming language; for example, 68000 assembly language, C, C++, Pascal, Fortran and the like. Suitable program code is entered into a single file, or multiple files, using a conventional text editor and stored or embodied in a computer-readable medium, such as the hard disk drive 74. If the entered code text is in a high level language, the code is compiled and the resultant compiler code is then linked with an object code of precompiled Windows® library routines. To execute the linked and, compiled object code the system user invokes the object code, causing the CPU 70 to load the code in RAM 72. The CPU 70 then reads and executes the code to perform the tasks identified in the program.

Although the invention has been described in terms of specific embodiments, one skilled in the art will recognize that various changes to the reaction conditions, i.e.,

temperature, pressure, film thickness and the like can be substituted and are meant to be included herein. Additionally, while the deposition process has been described as occurring in the same chamber, it may be bifurcated. In this manner, the nucleation layer may be deposited in one chamber and the bulk deposition occurring in a differing
5 chamber, located within the same mainframe deposition system. However, the bulk deposition may occur in a processing chamber of a mainframe deposition system that is different from the mainframe deposition system in which the processing chamber is located that is employed to deposit the nucleation layer. Finally, other refractory metals may be deposited, in addition to tungsten, and other deposition techniques may be
10 employed in lieu of CVD. For example, physical vapor deposition (PVD) techniques, or a combination of both CVD and PVD techniques may be employed. The scope of the invention should not be based upon the foregoing description. Rather, the scope of the invention should be determined based upon the claims recited herein, including the full scope of equivalents thereof.

WHAT IS CLAIMED IS

1 1. A method for forming a layer on a substrate disposed in a
2 processing chamber, said method comprising:
3 forming a nucleation layer by serially exposing said substrate to first and
4 second reactive gases; and
5 forming atop of said nucleation layer, a bulk deposition layer employing
6 vapor deposition to subject said nucleation layer to a bulk deposition of a compound
7 contained in one of said first and second reactive gases.

1 2. The method as recited in claim 1 wherein forming atop of said
2 nucleation layer includes forming said bulk deposition layer employing chemical vapor
3 deposition.

1 3. The method as recited in claim 1 wherein forming atop of said
2 nucleation layer includes forming said bulk deposition layer employing physical vapor
3 deposition.

1 4. The method as recited in claim 1 wherein forming a nucleation
2 layer further includes introducing said first and second gases therein so as to purge said
3 processing chamber of said first reactive gas by introducing a purge gas therein, before
4 exposing said substrate to said second reactive gas.

1 5. The method as recited in claim 1 wherein forming a nucleation
2 layer further includes purging said processing chamber of said first reactive gas by
3 pumping said processing chamber clear of all gases disposed therein before introducing
4 said second reactive gas.

1 6. The method as recited in claim 1 wherein forming a nucleation
2 layer further includes purging said processing chamber of said first reactive gas by
3 introducing a purge gas subsequently pumping said processing chamber clear of all gases
4 disposed therein before exposing said substrate to said second reactive gas.

1 7. The method as recited in claim 1 wherein forming a nucleation layer
2 includes forming alternating layers of a boron-containing compound and a refractory metal
3 compound onto said substrate.

1 8. The method as recited in claim 7 wherein the boron-containing
2 compound is diborane B₂H₆.

1 9. The method as recited in claim 7 further including subject said
2 substrate to a purge gas following formation of each of said alternating layers.

1 10. A method for forming a layer on a substrate, said method comprising:
2 serially exposing said substrate to first and second reactive gases, while said
3 substrate is disposed in a processing chamber, to form a nucleation layer;
4 removing from said processing chamber said first reactive gas before exposing
5 said substrate to said second reactive gas;
6 forming said layer adjacent to said nucleation layer by chemical vapor
7 deposition while said substrate is disposed in said processing chamber by concurrently
8 exposing said nucleation layer to said second reactive gas and a reducing agent.

1 11. The method of claim 10 wherein said second reactive gas includes a
2 refractory metal and said reducing agent includes silane.

1 12. The method of claim 11 wherein said refractory metal is selected from
2 the group consisting of titanium (Ti) and tungsten (W).

1 13. The method of claim 10 wherein removing from said processing
2 chamber further includes introducing a purge gas into said processing chamber and pumping
3 said first processing chamber clear of all gases present therein.

1 14. The method as recited in claim 10 wherein said nucleation layer has a
2 thickness in the range of 10 to 100 Å.

1 15. A processing system for processing a substrate in a processing
2 chamber, said system comprising:
3 means for forming a nucleation layer by serially exposing said substrate to
4 first and second reactive gases; and

means for forming, atop of said nucleation layer, a bulk deposition layer employing vapor deposition to subject said nucleation layer to a bulk deposition of a compound contained in one of said first and second reactive gases.

16. A processing system for a substrate, said system comprising:
a body defining a processing chamber;
a holder, disposed within said processing chamber, to support said substrate;
a gas delivery system in fluid communication with said processing chamber;
a temperature control system in thermal communication with said processing chamber;
a pressure control system in fluid communication with said processing chamber;
a controller in electrical communication with said gas delivery system, said temperature control system, and said pressure control system; and
a memory in data communication with said controller, said memory comprising a computer-readable medium having a computer-readable program embodied therein, said computer-readable program including a first set of instructions for controlling said gas delivery system to form a nucleation layer by serially exposing said substrate to first and second reactive gases, and a second set of instructions to control said gas delivery system to form, top of said nucleation layer, a bulk deposition layer by subjecting said nucleation layer to vapor deposition of a compound contained in one of said first and second reactive gases.

17. The processing system as recited in claim 16 wherein said computer-readable program includes an additional set of instructions to purge said processing chamber of said reactive gas before introducing said second reactive gas by introducing a purge gas therein.

18. The processing system as recited in claim 16 wherein said computer-readable program includes an additional set of instructions to purge said processing chamber of said first reactive gas before introducing said second reactive gas by pumping said first processing chamber clear of all gases disposed therein.

19. The processing system as recited in claim 16 wherein said first reactive gas includes a boron compound and said second reactive gas includes a refractory metal

3 compound with said refractory metal compound being from the group consisting of titanium
4 and tungsten and said purge gas being from the group consisting of nitrogen, hydrogen and
5 argon.

1 20. The processing system as recited in claim 16 wherein said computer-
2 readable program includes an additional set of instructions to purge said processing chamber
3 of said first reactive gas before introducing said second reactive gas by introducing a purge
4 gas therein and subsequently pumping said first processing chamber clear of all gases
5 disposed therein.

5 **METHOD AND APPARATUS FOR DEPOSITING REFRACTORY METAL
LAYERS EMPLOYING SEQUENTIAL DEPOSITION TECHNIQUES TO FORM A
NUCLEATION LAYER**

ABSTRACT OF THE DISCLOSURE

10 A method and system to form a refractory metal layer on a substrate features
nucleating a substrate using sequential deposition techniques in which the substrate is serially
exposed to first and second reactive gases followed by forming a layer, employing vapor
deposition, to subject the nucleation layer to a bulk deposition of a compound contained in
one of the first and second reactive gases.

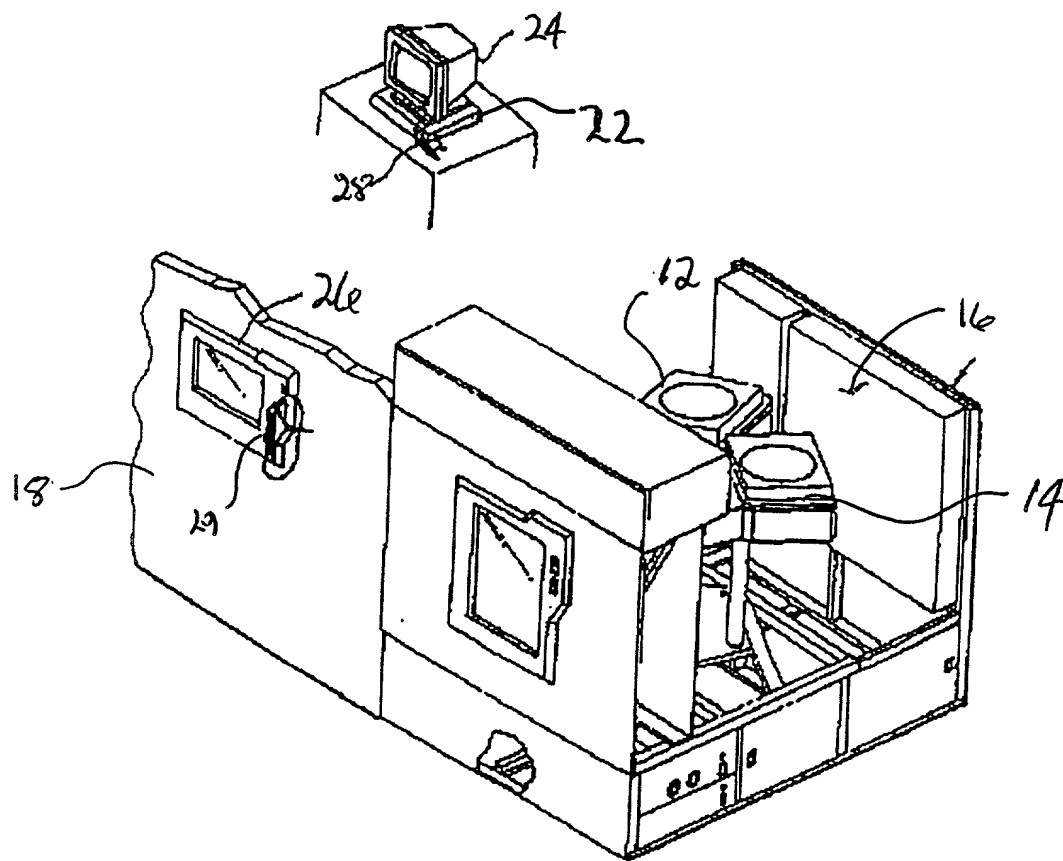


Fig. 1

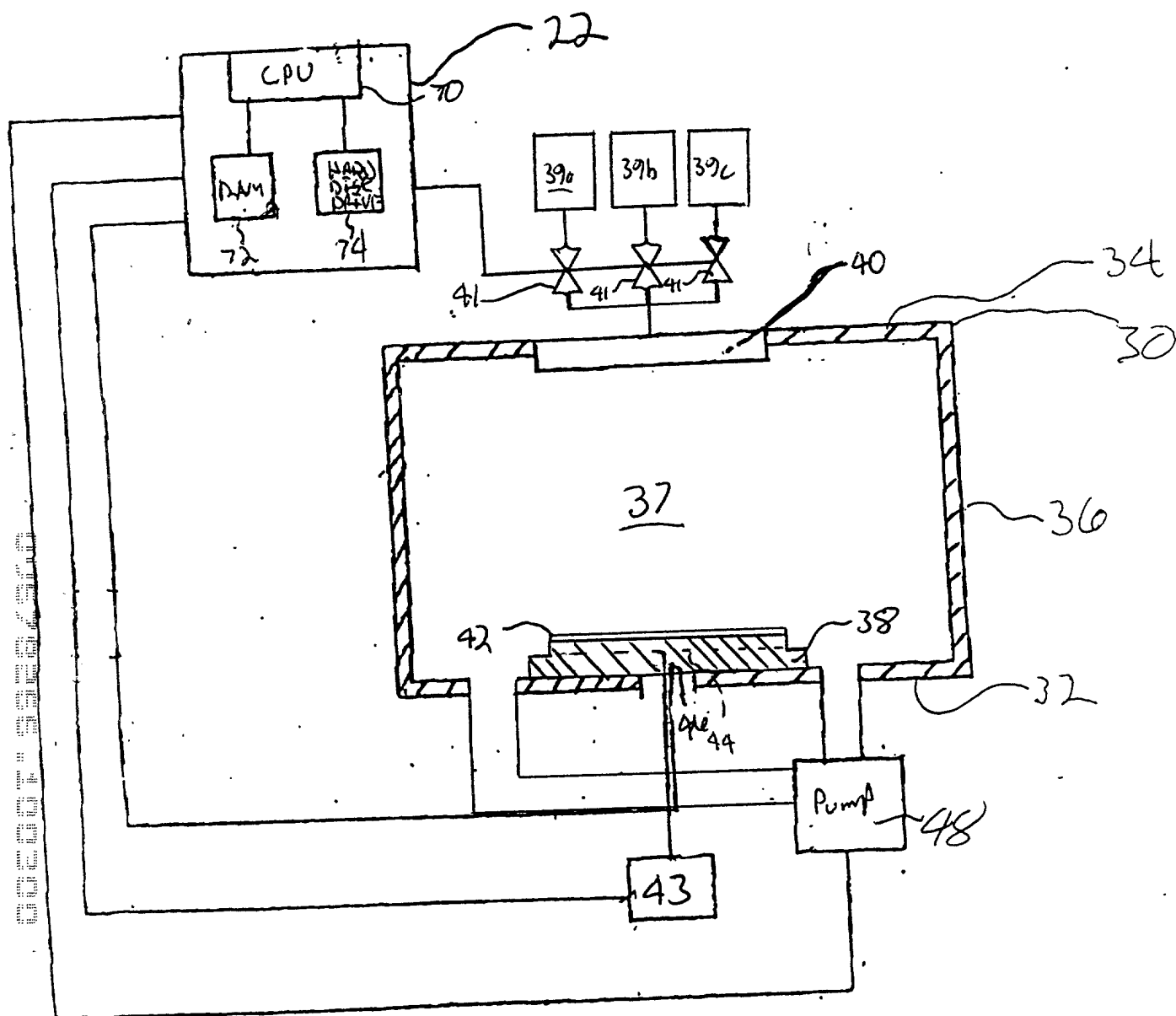


Fig. 2

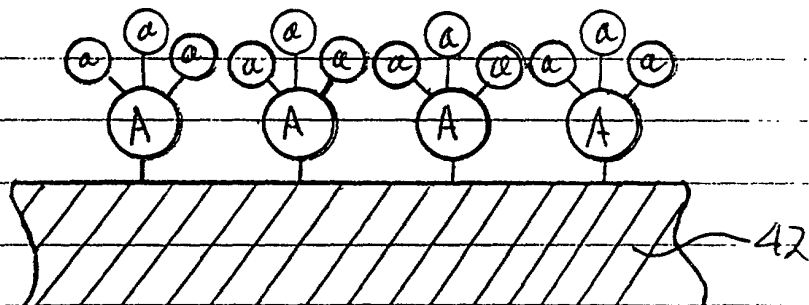
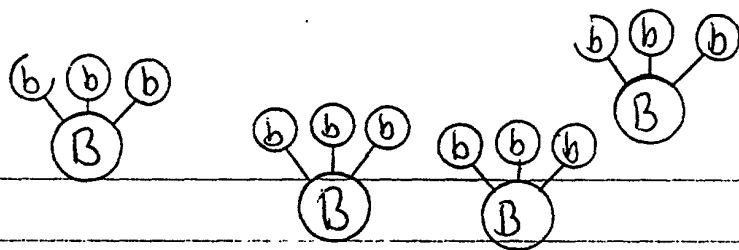


FIG. 3

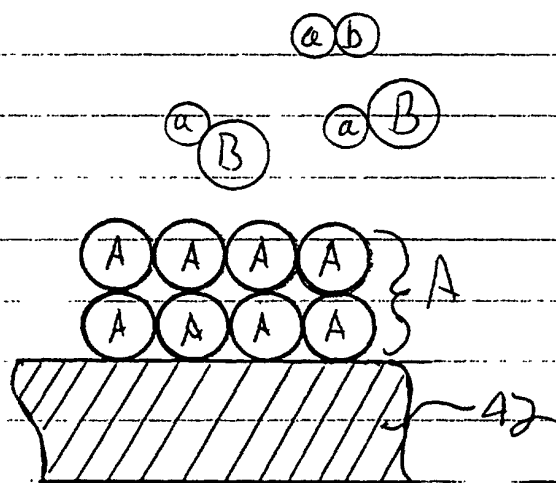


FIG. 4

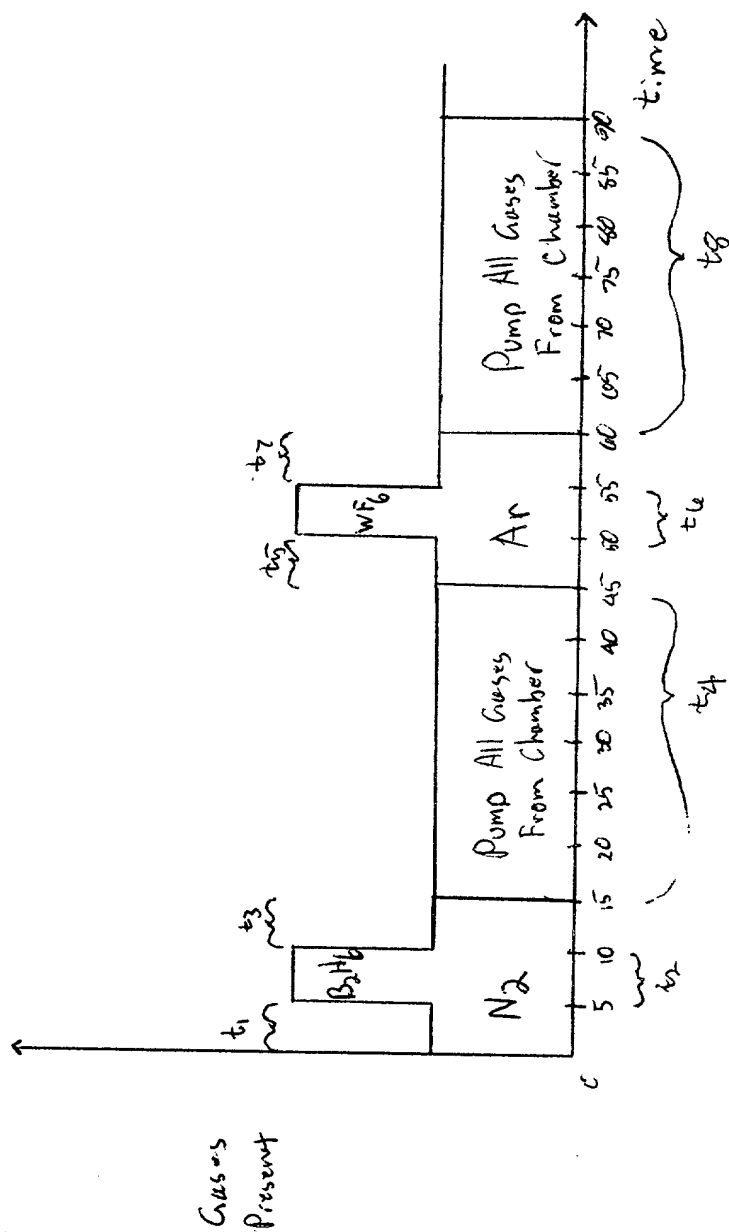


Fig. 5

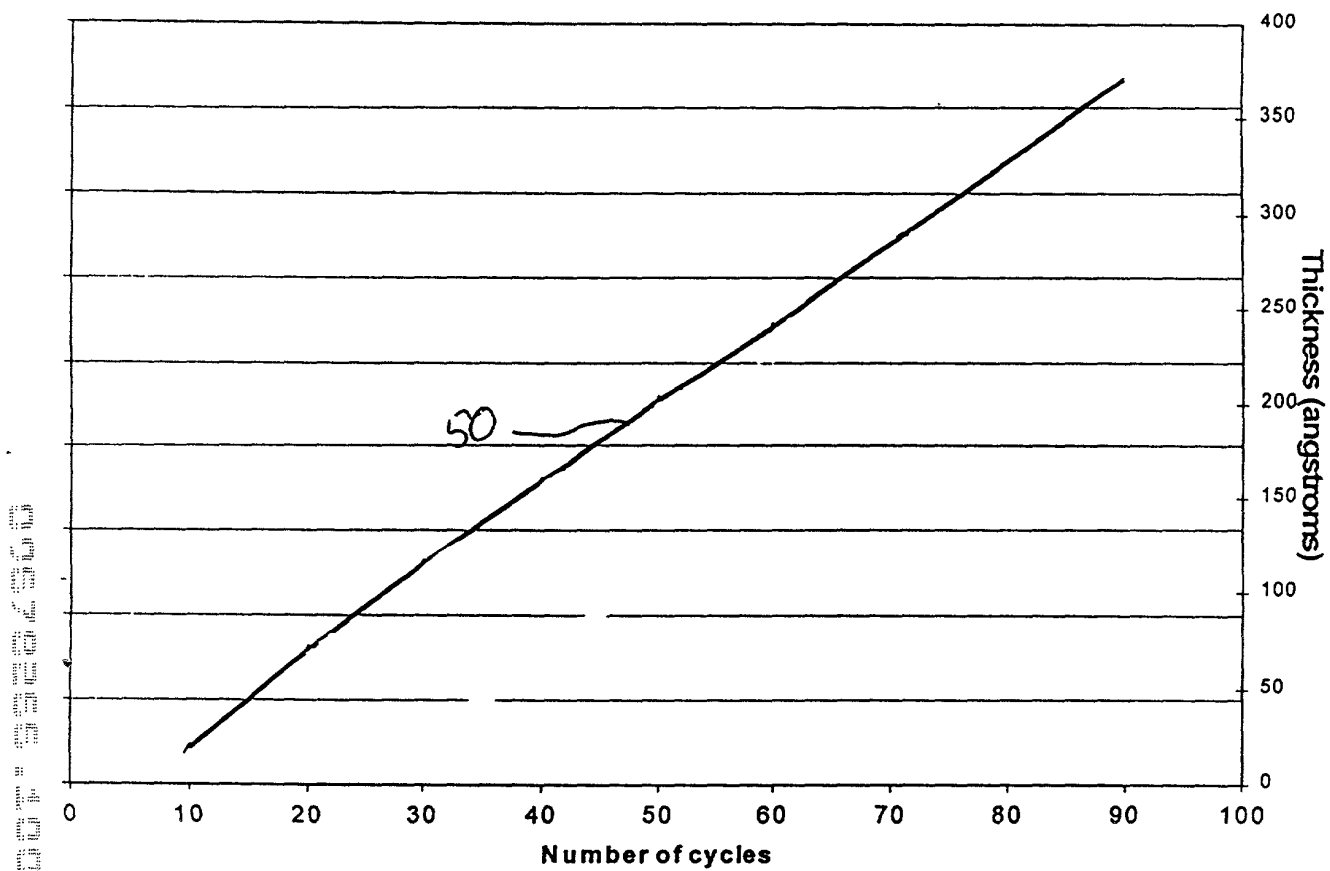


Fig. 6

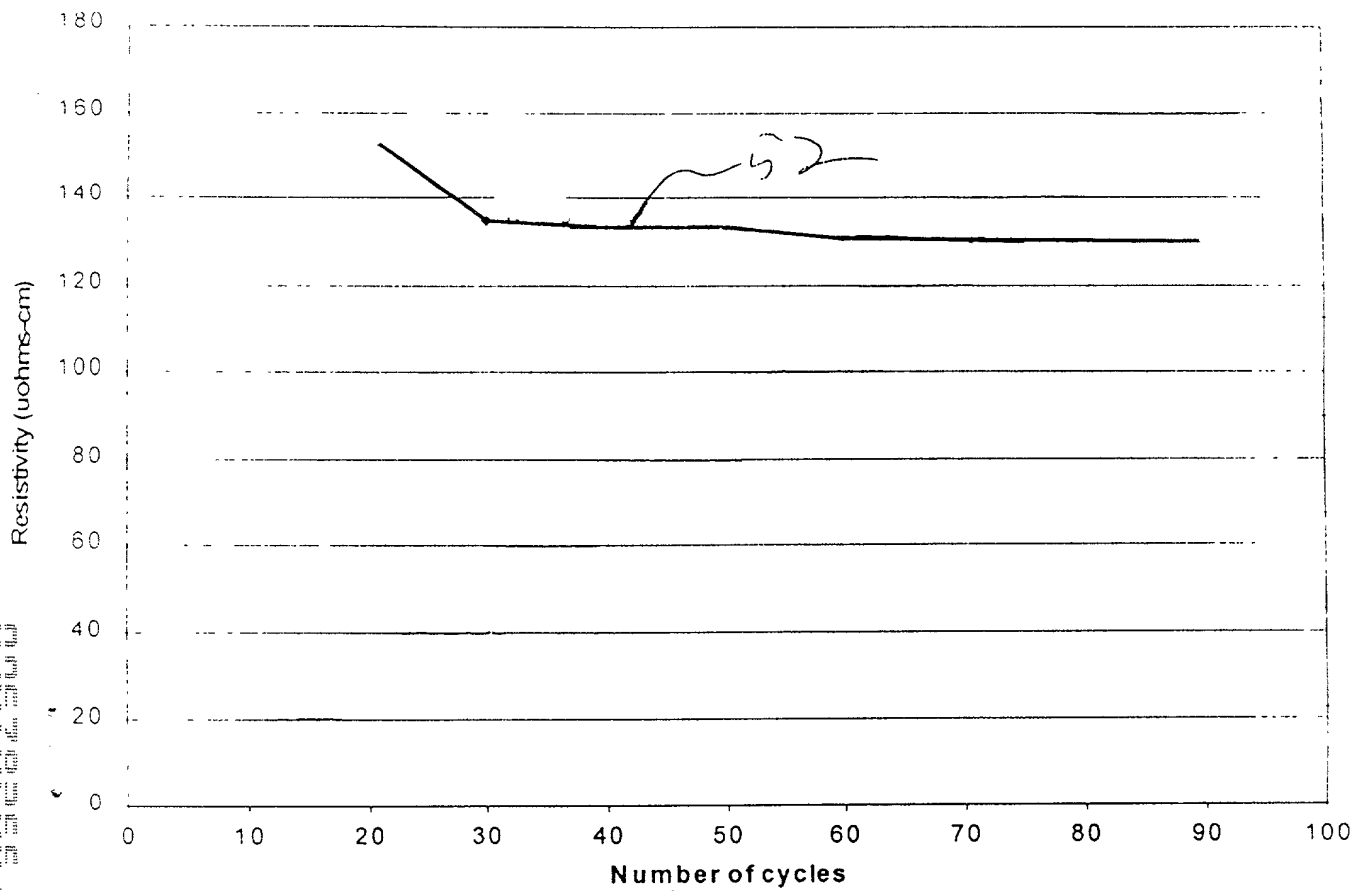


FIG. 7

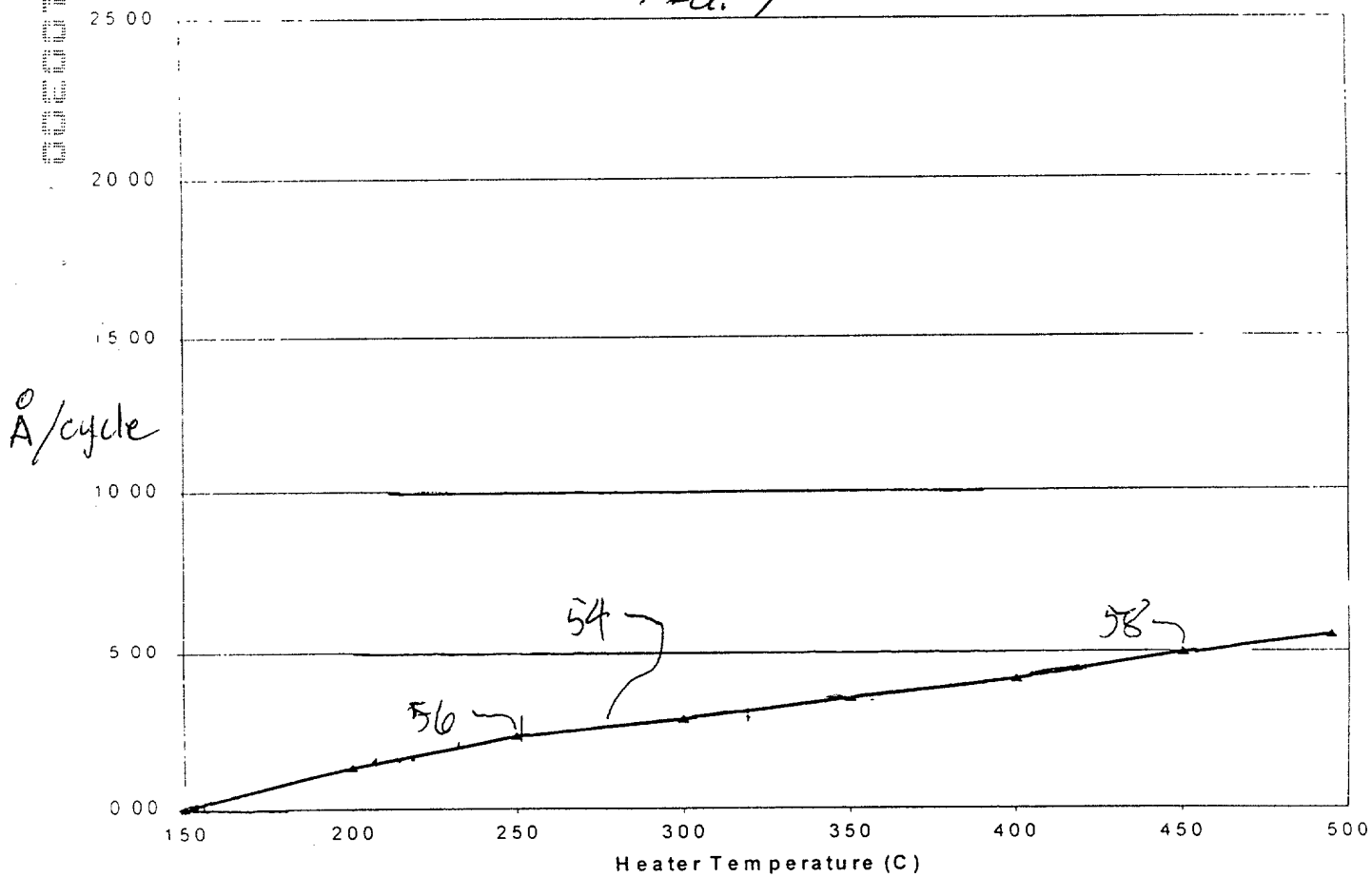


FIG. 8

μΩ-cm

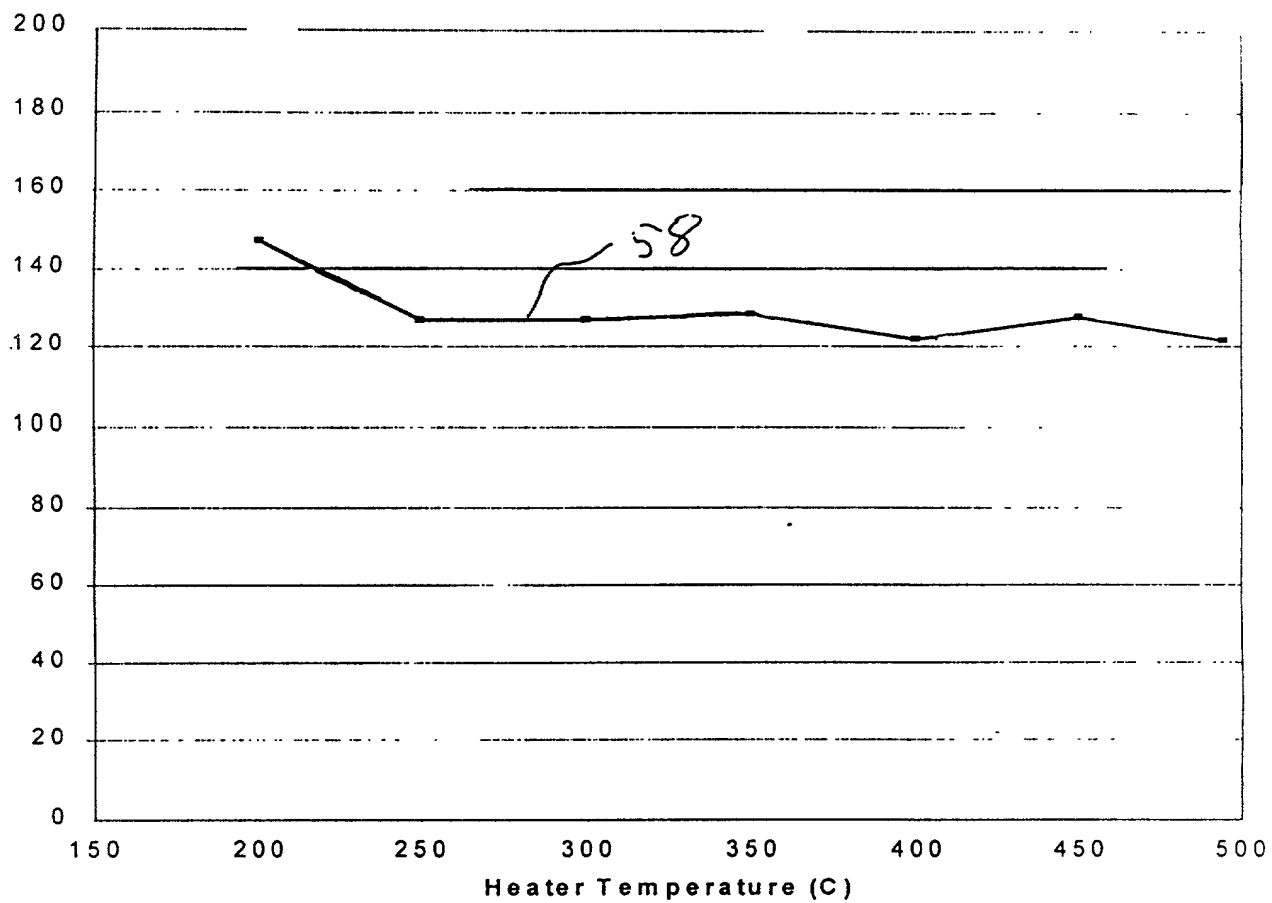


Fig. 9

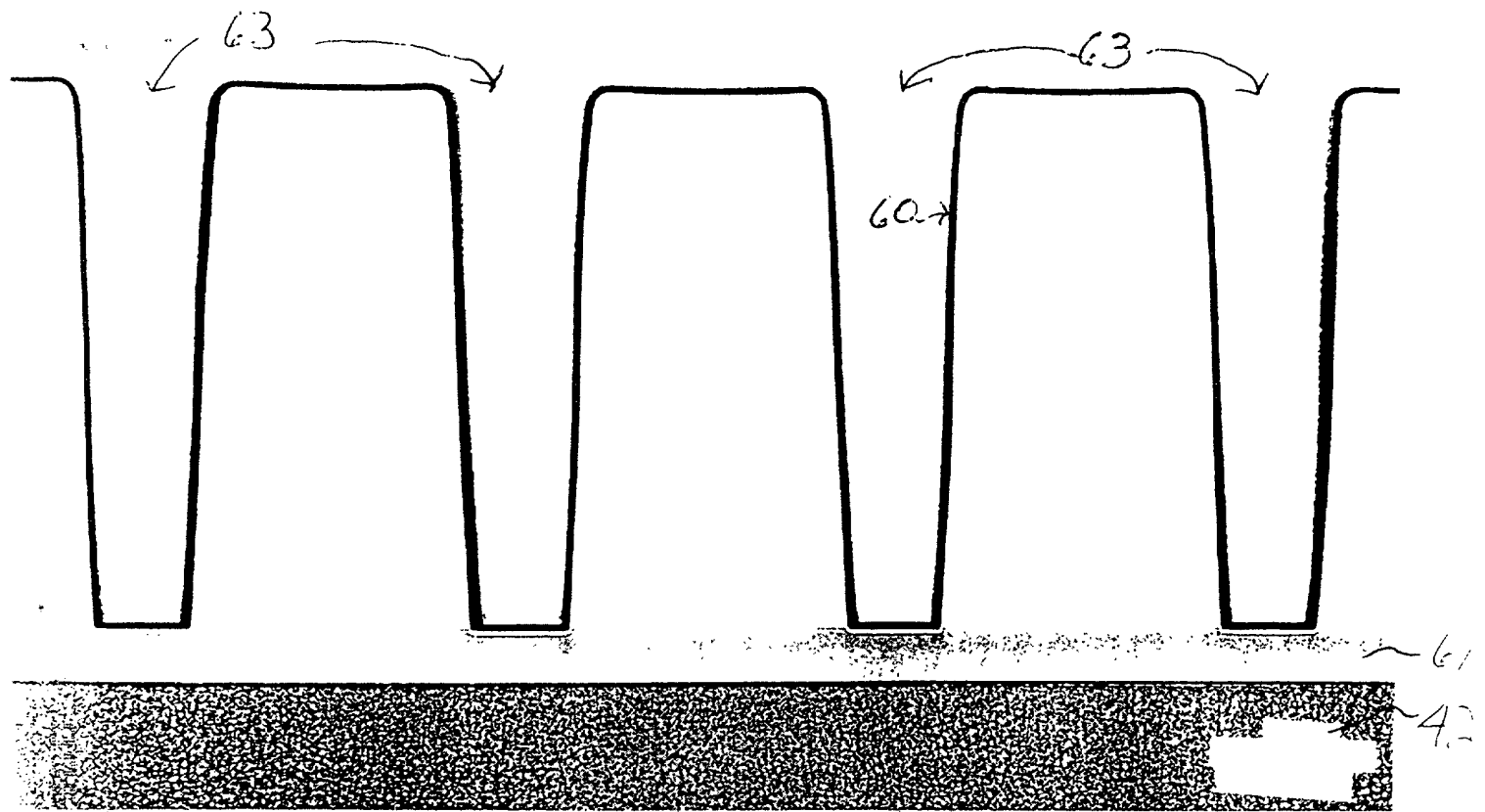


Fig. 10

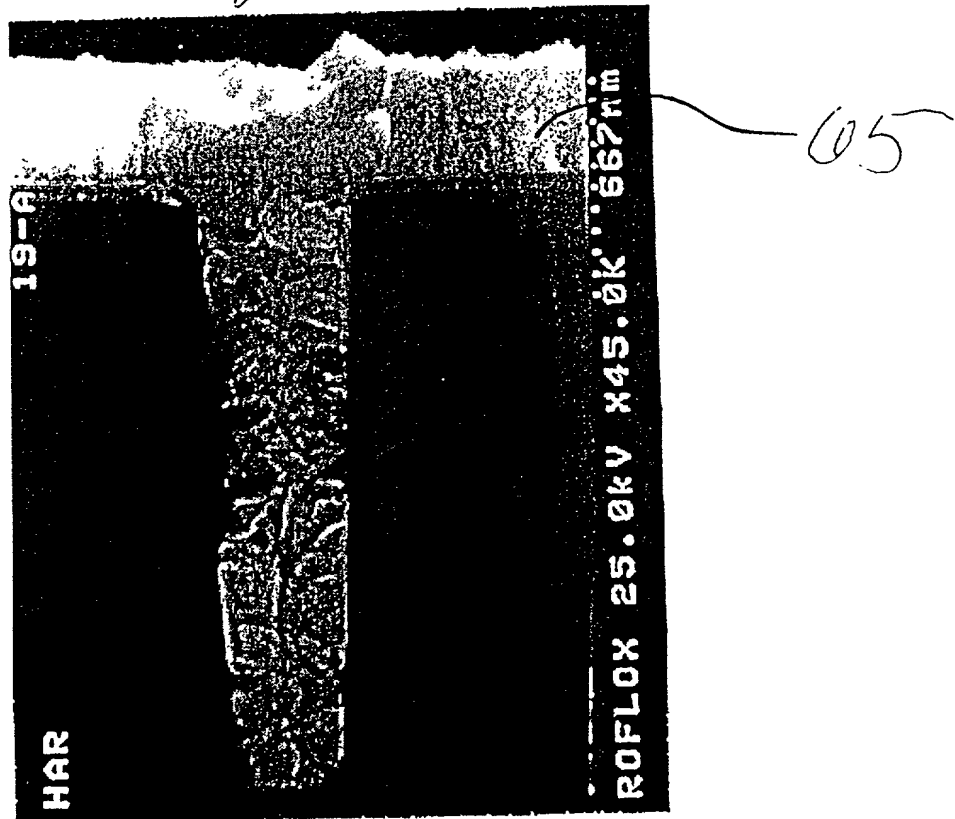


Fig. 11

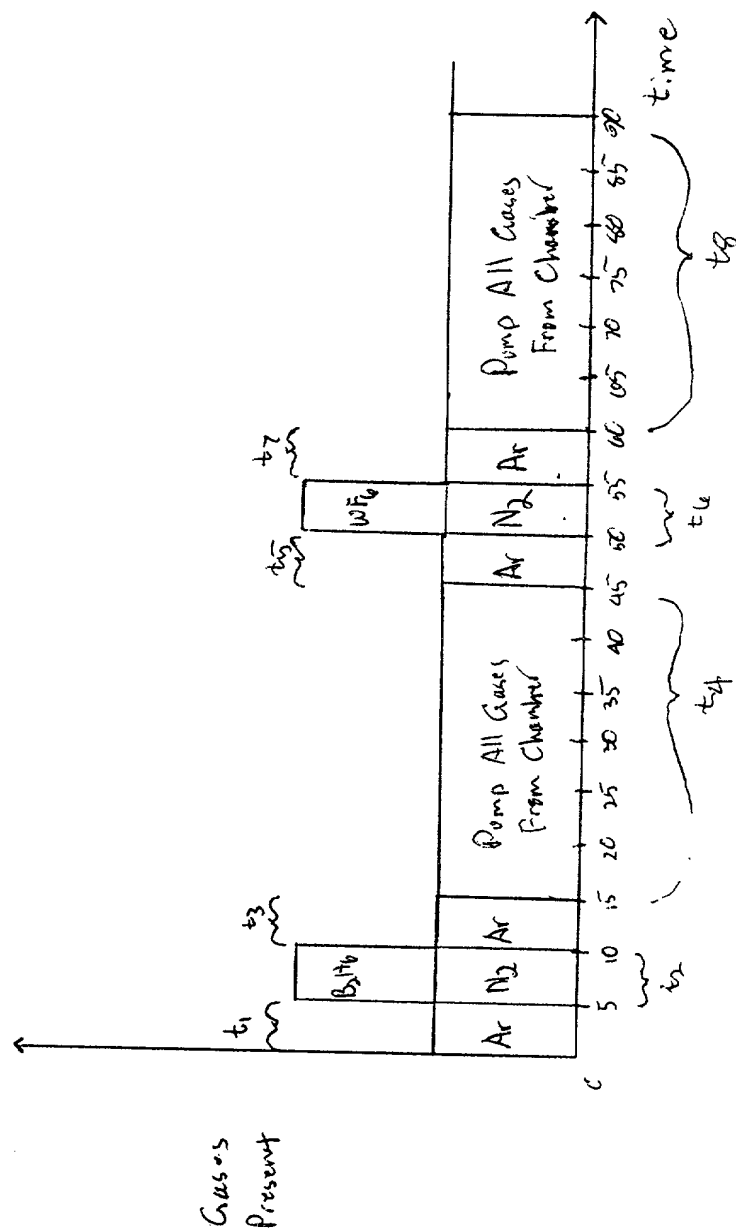


Fig. 12

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

This declaration is of the following type:

- ☐ original
- ☐ divisional
- ☐ continuation
- ☒ continuation-in-part

**MING XI, ASHOK SINHA, MORIS KORI, ALFRED W. MAK, JEONG SOO BYUN, LAWRENCE
CHUNG-LAI LEI, AND HUA CHUNG**

My residence, post office address and citizenship are as stated below next to my name. I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

**METHOD AND APPARATUS FOR DEPOSITING REFRACTORY METAL LAYERS EMPLOYING
SEQUENTIAL DEPOSITION TECHNIQUES TO FORM A NUCLEATION LAYER**

SPECIFICATION IDENTIFICATION

The specification of which:

- ☒ is attached hereto
- ☐ was filed on _____, under Express Mail No. _____ (as Serial No. not yet known) and was amended on _____ (if applicable)
- ☐ was described and claimed in PCT International Application No. _____ filed on _____ and as amended under PCT Article 19 on _____.

ACKNOWLEDGMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information I know to be material to patentability in accordance with Title 37, Code of Federal Regulations, 1.56,

and which is material to the examination of this application; namely, information where there is a substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent, and

- ☐ In compliance with this duty there is attached an Information Disclosure Statement in accordance with 37 CFR 1.98.

PRIORITY CLAIM (35 U.S.C. §119)

I hereby claim foreign priority benefits under Title 35, United States Code, §119, of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America or of any United States Provisional Application(s) listed below, and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

- ☒ No such applications have been filed.
☐ Such applications have been filed as follows:

A. Prior foreign/PCT/provisional application(s) filed within 12 mos. (6 mos. for design) prior to this application, and any priority claims under 35 U.S.C. § 119

<u>Country/PCT</u>	<u>Application No</u>	<u>Date Filed</u>	<u>Priority Claimed</u>
			<input type="checkbox"/> Yes <input type="checkbox"/> No
			<input type="checkbox"/> Yes <input type="checkbox"/> No

B. All foreign application(s), if any, filed more than 12 mos. (6 mos for design) prior to this U.S. application

Country:
Application No:
Filing date:

PRIORITY CLAIM (35 U.S.C. §120)

I hereby claim the benefit under Title 35, United States Code, § 120, of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information that is material to the examination of this application (namely, information where there is substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application.

- ☐ No such applications have been filed
☒ Such applications have been filed, as follows:

<u>Serial No.</u>	<u>Filing Date</u>	<u>Status</u>	
		<u>Patented Pending</u>	<u>Abandoned</u>
09/605,593	6/28/2000	Pending	

POWER OF ATTORNEY

I hereby appoint the following attorneys and/or agents to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

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Donald Verplancken	Registration No. 33,217
Lawrence Edelman	Registration No. 25,226
Michael B. Einschlag	Registration No. 29,301
Joseph Bach	Registration No. 37,771
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Law Office of Kenneth C. Brooks
512 527-0104

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and, further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Sec. 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patents issued thereon.

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Country of Citizenship: People's Republic of China

Full name of second inventor: Ashok Sinha

Inventor's signature: _____ Date: _____

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Full name of third inventor: Moris Kori

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Full name of fourth inventor: Alfred W. Mak

Inventor's signature: _____ Date: _____

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Full name of fifth inventor: Jeong Soo Byun

Inventor's signature: _____ Date: _____

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Country of Citizenship: South Korea

Full name of sixth inventor: Lawrence Chung-Lai Lei

Inventor's signature: _____ Date: _____

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Country of Citizenship: U.S.A.

Full name of seventh inventor: Hua Chung

Inventor's signature: _____ Date: _____

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Country of Citizenship: Republic of China

(Declaration ends with this page)